Proposed Research

UV Laser Refurbishment for Milling Research-Grade Diamonds

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Introduction

The GlueX experiment is a primary scientific motivation for the upgrade of the CEBAF electron accelerator at Jefferson Lab from 6 to 12 GeV. The upgrade project is the top priority in the funding plan for the US Department of Energy facilities for Nuclear Physics during the present decade. The purpose of the GlueX experiment is to reveal the role played by hidden nuclear particles called gluons in the structure and dynamics of nuclei. Even though gluons are responsible for more than 99% of the mass of ordinary matter, very little is known about the way they behave when they are excited. In the GlueX (gluon excitation) experiment, the nuclear glue is excited by shining a polarized beam of light on a hydrogen target and detecting the radiation that is produced in a magnetic spectrometer. To excite the gluons, the light beam must have a wavelength that is significantly smaller than the size of the nucleus itself, which implies that the beam energy must be very high. This light beam is produced by passing a high-energy electron beam through a specially prepared diamond crystal known as a “radiator”. Optimal performance of this source requires a supply of very thin diamond radiators with near-perfect crystalline quality.

Recent advances in the quality of synthetic diamond monocrystals produced using the method of chemical vapor deposition (CVD) have brought the price of research-grade diamond monocrystals down to the point where it is possible for the first time to engineer diamond radiators according to predefined specifications on crystal quality [1]. The group led by the PI has expertise in diamond characterization using X-ray beams at synchrotron light sources [2]. Diamond crystals of the essentially perfect crystal quality are now available commercially from the firm Element Six at a cost of less than $1000 for a 4mm x 4mm sample. What is not so well developed at present is the ability to machine diamond monocrystals at the micron length scale without damaging the underlying crystal. Element Six is able to polish the samples they sell, but their technique is limited to thicknesses greater than 50 microns. The requirement for GlueX radiators is that the diamond be only 20 ± 1 microns thick. The goal of this project is to develop the capability and equipment within the UConn Physics Department to be able to machine diamond monocrystals with micron accuracy.

Technology for Thinning Diamonds

The high-quality synthetic monocrystals that are available from Element Six are grown as large three-dimensional crystals from which slices are cut using a high-power infrared laser. Once they are sliced off, the manufacturer polishes the slices to remove the damaged surface from the cutting laser, and they are sold as planar wafers of a few mm on a side and a few hundred microns thick. If desired, the Element Six has the capability to continue the polishing process until the diamond thickness is reduced to less than 100 microns, with an ultimate limit of about 50 microns. Below this thickness, there is serious risk of breakage from the mechanical stresses of the process. Several attempts have been made to go beyond the 50 micron limit using this process, and after several failed attempts one 20 micron sample was obtained, but it turned out to be badly warped and in the end proved to be unusable. The thinnest usable samples that have been produced using standard thinning techniques have been close to 50 microns in thickness, more than a factor of two thicker than the goal of 20 microns for GlueX.

Within the last two years, researchers at Brookhaven National Lab have been actively working on thinning diamonds for a different application. They are working on the development of a diamond amplifier for use in a high-current source for an energy-recovery linac. Although they are very different, this application has many of the same requirements for diamond crystal quality and thickness as GlueX. In fact, their goal is also to produce a self-supporting diamond monocrystal with an area approaching a square cm and a thickness of 20 microns. To achieve this goal, the BNL group has developed capability and techniques in-house for thinning diamonds using laser ablation. Much of this work is too new to have been published yet. The PI has made a series of visits to Brookhaven to speak with the diamond development group there and to see their setup. The sample is mounted in a computer-controlled *XY* translation stage which holds the diamond in a precise position with respect to the beam. The laser produces a beam of 192 nm light (excimer ArF source) which is focused using a fused silica lens down to a spot on the diamond that is approximately 200 microns x 50 microns. The power in each laser pulse is monitored using a sensor and fed back to the power supply to maintain the desired power level for ablation. The translation stage moves the sample in a raster pattern across the beam, with a step size much smaller than the beam spot in order to ensure as flat as possible a cut surface.

The BNL group has carefully optimized the parameters of the ablation procedure to minimize the roughness of the final cut surface and maximize the cutting rate. They found that the power required to attain a given cutting rate is somewhat lower for the polycrystalline samples that they first tested than for the monocrystals that they tested more recently. All of these results have been reported internally, and will eventually be published for the benefit of other groups such as GlueX.

Synergies at the University of Connecticut

There is significant experience with high-power UV lasers within the experimental groups in the Physics Department at the University of Connecticut. The Condensed Matter research group of Prof. Barry Wells operates a large KrF excimer laser for electronic studies of superconductors. Although this laser could be reconfigured to work at the shorter 192 nm wavelength, it is in active use for the on-going condensed matter research program of the lab. However, there is space and infrastructure in the lab to support a second excimer laser setup. The fluorine gas used in excimer lasers is extremely reactive, so setting up a fluorine gas handling system requires capability for both storage and distribution and for venting of waste gases from the laser. Prof. Wells has offered to the PI sufficient space in his lab and connections to his gas handling and ventilation systems for the setup presented in this proposal. There is a strong possibility that his group may wish to have access to the 192 nm beam from this setup for certain experiments that they plan to carry out in the future. This shared use of the laser makes sense, given the need by GlueX to have only intermittent access to it in order to produce new radiators as needed throughout the lifetime of the experiment.

For the laser itself, the Atomic and Molecular Optics research group of Prof. Ed Eyler has an older excimer laser that is configured for use at the 192 nm wavelength that he is willing to provide to the P.I. on an indefinite loan basis. This laser has been used by his group in the past, but has been idle for about 10 years, as his research has not required it. The laser is still configured as it was when it was last used. Its gas connections were flushed with dry nitrogen after its last use to prevent corrosion due to long-term exposure to fluorine gas. Some degradation of the vacuum seals is expected after so long a period without use, but the primary components are expected to be in working order. Once it passes an initial checkout in its present location, it will be dismantled and moved to its new location in Prof. Wells' lab where the diamond ablation work will be carried out.

Other Funding Sources

Diamond crystals of sufficient area for use as coherent bremsstrahlung radiators are currently available from Element Six at a cost on the order of $1K apiece. Funding for a handful of these radiators is already present in the construction budget for the GlueX beam line, but there is at present no budget in place for thinning them. The budget in this proposal covers only the optics and translation stage for the diamond ablation facility, together with refurbishment of the existing excimer laser and its integration with the existing infrastructure in the excimer laser lab at the University of Connecticut. Internal funding is sought for this project because the scale of the large faculty grant matches the project budget, and because of the immediate opportunities that exist to take advantage of synergies at the University of Connecticut.

Risk Assessment and Evaluation Plan

Installation of major instrumentation related to the photon beam in Hall D is scheduled to begin in 2011 and continue into 2013 with the commissioning of the GlueX experiment. By the time that commissioning begins, it is important that basic radiator production issues have been resolved, and that the GlueX beam group be able to devote its resources to supporting operations. It makes sense in the year 2010 to devote resources to working out radiator production methods that will guarantee a reliable supply of radiators throughout the lifetime of the GlueX experiment. A reliable source for the raw diamond material has been found in Element Six, and reliable methods for assessing the quality of individual samples using X-rays has already been demonstrated. What is missing in the procurement pipeline for diamond radiators is the capability to thin them all the way down to 20 microns from the starting thickness of 200 – 300 microns. Without this capability, the experiment risks having to run at substantially decreased beam polarization, leading to reduced sensitivity to the experimental signals of gluonic excitations.

BNL researchers have demonstrated a timely and cost-effective thinning technique based on laser ablation. They are unable to commit to providing GlueX with a diamond thinning service that can meet our needs over the long run, but in the near term they are willing to cooperate with GlueX in helping us to reproduce their capabilities. In this context, it is not likely that unforeseen technical obstacles will emerge that will prevent this technique from producing usable radiators.

Furthermore, unlike the lapping technique used by Element Six, which can only produce radiators with nominally uniform thickness, laser ablation can be used to produce radiators with an arbitrary thickness profile. This might be exploited to produce diamonds that are thicker along the edges than in the middle, which might be more stiff and this less susceptible to the kind of warping strains that ruined the usefulness of the original 20 micron radiator obtained from Element Six. Thus, the use of the laser ablation thinning technique reduces the risk that a 20 micron diamond will be difficult to mount on a free-standing fixture without distorting its natural shape.

The UConn group has ongoing access to the X-ray beam line C at CHESS that is configured for crystal diffraction. This facility is essential to the success of this project.
X-ray rocking curve measurements of the diamonds before and after thinning are the only reliable way known to determine whether the quality of a diamond has changed during a processing step. The GlueX group is presently working with the BNL diamond R&D group to measure the quality of a diamond monocrystal before and after it is subjected to thinning by ablation. Demonstration of successful thinning of diamond radiators will only be complete when rocking curves of the thinned radiator show that it has essentially the same mosaic spread as had the original raw sample. The measurable outcome from this project will be the demonstration of thinning of one diamond monocrystal from an initial thickness of several hundred microns down to 20 microns, together with X-ray measurements at CHESS verifying that the thinning process did not appreciably degrade the quality of the final product. A progress report on this work will be made at the annual Conference on Diamond and Diamond-Related Materials in September 2010. Final results will be published in the journal Nuclear Instruments and Methods in Scientific Research.

Summary

The GlueX experiment is a critical part of the US effort in accelerator-based nuclear science for the coming decade. Provision of a reliable method for production of diamond radiators is essential to the success of this experiment. With recent advances in the production of high-quality synthetic diamonds, the raw material for radiators is not a problem for the experiment, but at this point no known industrial firm has demonstrated ability to thin these diamonds down to the requisite thickness. With the pioneering work of the diamond R&D group at BNL, this capability can be erected at the University of Connecticut for a relatively modest cost. The cost is further reduced by the availability at UConn of an excimer laser with enough power to cut diamond. This proposal seeks funds to refurbish this laser, demonstrating that the laser ablation method meets the requirements of the GlueX experiment, and developing expertise and infrastructure at UConn for this unique technology.

References

[1] G. Scarsbrook, Element Six Ltd, 20th European Conference on Diamond, Diamond-Like Materials, Carbon Nanotubes, and Nitrides, Athens, Greece, September 6-10, 2009. Proceedings to be published by Elsevier.

[2] J.D. Kellie et.al, *Nucl.Instr.Meth.* **A**545 (2005) 164.